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Spatial Temporal Distribution of Selected Heavy Metals in an Urban Stream: Case Study of Sosiani River in Eldoret Municipality Kenya

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Abstract
This study aimed at assessing the seasonal and longitudinal variations in four selected heavy metals associated with industries in Eldoret Municipality along Sosiani River in Uasin Gishu County. An experimental design was used to collect water samples upstream midstream and downstream of Eldoret town. Samples were collected from 13 different effluent discharge points in accordance to APHA, 2012 water sampling procedures along the river for a period of one year during the dry and wet seasons. The heavy metals were analysed using an Atomic Absorption Spectrophotometer (ASS Spectronic 21D) flame atomizer method. Results were analysed using SPSS version 20 for ANOVA and correlation analysis. Sosiani River exhibited both seasonal and spatial distribution of these heavy metals. The concentrations were lowest upstream at the source of the river but increased midstream as the river drained more effluent. However, they declined further downstream in Turbo town which perhaps suggests self purification ability of Sosiani River. There was significant variation in Zn levels ($F=305.70$ & $P< 0.001$), Cd levels ($F= 2.71$ $P<0.003$) Pb levels ($F= 72.26$ $P<0.001$) and Cr levels ($F=140.26$ $P<0.001$) along the river and with the onset of rainy season. Levels of Zn and Cr were below NEMA/WHO standards while Cd and Pb were above NEMA/WHO standards hence a health concern. The study recommends that Municipal effluent should be channelled into effluent treatment works for pre-treatment and all facilities discharging effluent should develop wetlands if not connected to the sewer line. ELDOWAS should include chemical treatment in Huruma sewage treatment plant to improve the efficacy of treatment of heavy metals and construct a wetland.

Key words: Sosiani River, water quality variations, Heavy metals

1. Introduction

Distribution of heavy metals in water is governed by dilution, dispersion, sedimentation and adsorption processes (Luoma & Rainbow, 2008). Heavy metals are among the major toxic pollutants in surface water due to their bio-accumulation, phyto-toxicity and health related effects on man. They are a problem in streams abutted by catchments with factories dealing with tanning, smelting, welding, renovation, manufacture and disposal of car batteries, petroleum and oil (Luoma & Rainbow, 2008). They have chronic and lethal effects and some are carcinogenic (Nabulo *et al.*, 2008; Varshney, 2008). Municipal effluent contains high concentrations of heavy metals which are toxic like Zinc, Cadmium, Copper, Lead, Mercury, Silver, Chromium and Nickel (Hammer & Hammer, 2001; McKinney & Schoch, 2003). Although food processing and textile industries produce effluent with high levels of heavy metals, domestic waste water is known to be the largest single source of heavy metals discharged into the environment (Pacyna, 2005). Faecal matter contributes 60 – 70 per cent of the load of Cd, Zn, Cu and Ni in domestic wastewater (Goel, 2006).

Cadmium has acute and long term toxicity in mammals and is a powerful mutagenic agent. It bio-accumulates in aquatic organisms, enters the food chain and interferes with metabolic processes in plants (Adriano, 2001). It can cause chronic obstructive pulmonary diseases, emphysema and chronic renal tubular disease in animals (Chennakrishnan *et al.*, 2008). Sources of cadmium are batteries, pigments, coatings and plating, and as stabilizers for plastics (Luoma & Rainbow, 2008; Apostolis *et al.*, 2007). Chromium on the other hand is discharged from diffuse sources and products such as preservatives, dying, and tanning activities. It is widely used as a tanning agent in leather processing (Zheng, 2007; David, 2008). Chromium poisoning causes skin allergy, it irritates the nose, lungs, stomach, intestines, convulsion, damage nose and lungs. Zinc originates from various products commonly used such as: insecticides, fungicides, wood preservatives, deodorants, cosmetics, medicines, ointments as antiseptic, paints, pigments, printing inks, colouring agent, tyres, batteries, plastics, rubber, paper, textiles, and cosmetics (Ulmgren, 2001). Acute toxicity from zinc results in tissue hypoxia as a consequence of cytological breakdown of gills (Burton & Robert, 2001). Lead poisoning causes neurodevelopment disorders, cardiovascular diseases, euceophalopathies, anaemia, renal malfunctioning and various endocrinal disorders especially of the reproductive glands hence impaired fertility (WHO, 2011).

2. Materials and Methods

This study was conducted along Sosiani River upstream midstream and downstream of Eldoret town in Uasin Gishu County of Kenya. Sosiani River discharges into Kipkaren River in Turbo which subsequently drains into Nzoia River a catchment of Lake Victoria (RoK, 2013). Eldoret town lies between latitude 00^0 03´S and 0^0 55 ´N and longitudes 34^0 50 ´E and 35^0 17 ´E (RoK, 2013). Sampling sites were selected at specific effluent discharge points at Zena flower farm, Sukunanga car wash, Municipal effluent discharge point at Kapsabet Bridge, effluent discharge point from Huruma dumpsite, Huruma sewage treatment plant and finally downstream in Turbo (Figure 1).

Composed water samples were collected and analyzed according to APHA, 2012 standard water sampling procedures. High density fluoropolymer bottles with Teflon lined caps were used in collecting grab water samples for laboratory analysis since metals sorb onto walls of glass bottles. These bottles were cleaned with phosphate free detergent and dilute hydrochloric acid to avoid metal contamination (APHA, 2012). The sampling sites were marked using a Geographic Positioning System (GPS) to enable replication. Composite samples were collected using half litre metal free Van Dorn bottles at a depth of 0.5m below water surface. Depth was important as it represents a homogenous water layer free from riverbed sediments and avoided atmospheric air interference. Samples were acidified with concentrated nitric acid to pH ≤ 2 to minimize precipitation and adsorption of metals on container walls and to inhibit bacterial growth that could lead to loss of metals. Nitric acid was a preferred matrix as it reduces interference by organic matter and converts metals associated with particulates (APHA, 2012). GFC Whatman filter paper was washed with water sample before and used to filter the acidified sample in the field. Samples collected were refrigerated but not frozen to minimize potential for volatilization or biodegradation. Freezing bottles crack and contaminate samples and also effects pH change. Thereafter standard solutions of each metal were prepared and used for calibrating the Atomic Absorption Spectrophotometer (ASS Spectronic 21D). They were then used to analyze heavy metals using flame atomizer method (at 2300^0C air-acetylene flame) which has higher precision than the graphite furnace method. Every metal has its own characteristic absorption wavelength (Cadmium 228.8nm, Chromium 357.9nm, Zinc 213.9nm and lead 510nm) hence a source lamp composed of that element was used. This made the method relatively free from spectral or radiation interferences. The amount of energy at the characteristic wavelength absorbed in the flame is proportional to the concentration of the element in the sample over a limited concentration range (APHA, 2012).

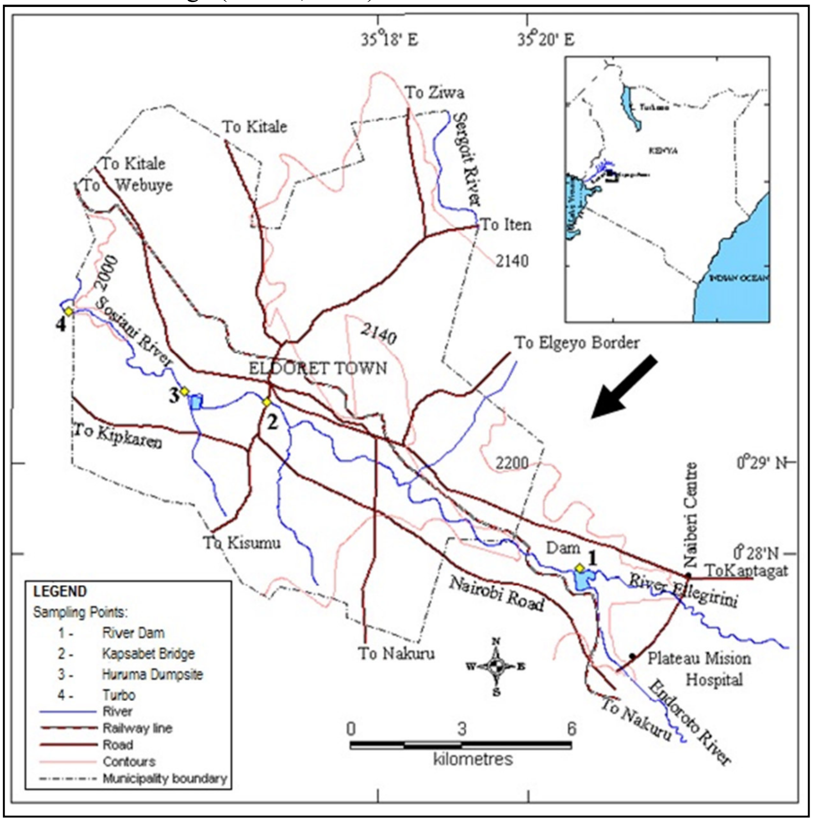

Figure 1: Map showing flow of Sosiani River
Source: Survey Data, 2016

3. Results and Discussion

The analysis of water samples indicates presence of Zn, Cr Cd and Pb heavy metals in Sosiani River which exhibited both seasonal and spatial distribution (Table 1). It was observed that the concentrations of the heavy metals was higher midstream in Eldoret CBD but lower at the source of the river at two river dam in Kaptagat and further downstream in Turbo town.

Table 1: Mean concentrations of heavy metals along Sosiani River

Sampling point	Zn (mg/L)	Cd (mg/L)	Pb (mg/L)	Cr (mg/L)
Two River Dam	0.096±0.009f	0.015±0.0015b	0.014±0.0014ef	0.002±0.0002c
Zena Flowers	0.093±0.0076f	0.034±0.006b	0.017±0.001e	0.007±0.0006bc
Sukunanga Car Wash	0.041±0.0028g	0.044±0.0073b	0.021±0.0019de	0.002±0.0003c
Munyaka Stream	0.173±0.0111e	0.043±0.0072b	0.015±0.0012e	0.004±0.0013bc
Car wash at Naivash	0.165±0.0058e	0.137±0.065a	0.032±0.0028bc	0.009±0.001b
Kapsabet bridge	0.455±0.0073a	0.067±0.0029ab	0.041±0.0022a	0.007±0.0005bc
Oldonyo dairies	0.239±0.0147d	0.044±0.0092b	0.026±0.0012cd	0.006±0.0007bc
Kipkaren bridge	0.415±0.0093ab	0.048±0.0055ab	0.002±0.0003h	0.007±0.0004bc
Raiply effluent	0.29±0.0064c	0.04±0.0077b	0.002±0.0003h	0.063±0.0043a
Bondeni Estate	0.034±0.0108g	0.07±0.0056ab	0.037±0.0017ab	0.008±0.001bc
Huruma sewage	0.386±0.0055b	0.037±0.0082b	0.014±0.0011e	0.004±0.0009bc
Huruma dumpsite	0.322±0.012c	0.028±0.0051b	0.006±0.0022fh	0.002±0.0004c
Turbo	0.015±0.001g	0.015±0.0026b	0.002±0.0002h	0.002±0.0002c
F value	305.70	2.71	72.26	140.26
p value	<0.001	0.003	<0.001	<0.001

Source: Survey Data, 2016

3.1 Variations in Zinc Levels

There was significant variation in Zinc levels in this river (F=305.70 & P< 0.001). The highest concentration of zinc in Sosiani River was at Kapsabet Bridge 0.455±0.007mg/L and at Kapkaren Bridge 0.415±0.009mg/L followed by Huruma sewage discharge point 0.386±0.006mg/L (Figure 2). Huruma dump site and Rai plywood had a moderately high concentration of zinc which was not significantly different among the two points. The lowest zinc concentration was at Turbo 0.015±0.001mg/L, Bondeni estate 0.034±0.011mg/L and Sukunanga car wash 0.041±0.003mg/L.

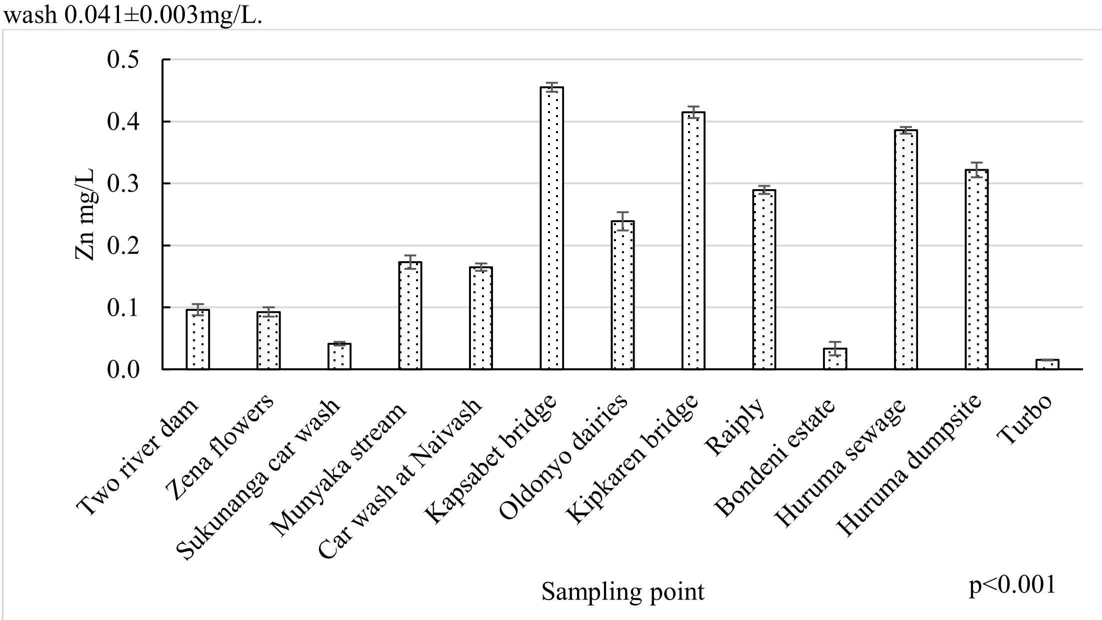

Figure 2: Zinc concentrations along Sosiani River
Source: Survey Data, 2016

Municipal effluent is a major source of Zinc in Sosiani River which is attributed to uncollected garbage containing Zinc products like old batteries. Further downstream in Turbo, the concentration of zinc significantly dropped to 0.015±0.001mg/L a sign that the river has self cleansing ability. The levels of Zinc increased with the rainy season though not significantly (P<0.151). However, it is observed that the concentration of Zinc at all sampling points was below the recommended NEMA standard value (1.5mg/L) and WHO standard value

(3mg/L) hence based on zinc levels the water is safe for human consumption. This is significant because Zinc imparts an undesirable astringent taste to water at a taste threshold beyond 4mg/L. Such water may appear opalescent and develop a greasy film on boiling (WHO, 2011).

These results are consistent with the findings of Jepkoech, 2013 whose study on Sosiani River showed no significant variations in mean concentrations of Zinc in sediments along the river (df=1, F=3.73, P=0.059). This was attributed to the fact that Zinc is one of the most soluble and mobile metal cation which is easily assimilated by plants hence low concentrations in sediments (Jepkoech, 2013).

3.2 Variations in Cadmium Levels

Cadmium concentrations varied significantly along Sosiani River (F= 2.71 P<0.003). Levels of cadmium were highest at Naivash carwash 0.137±0.065mg/L though it was not significantly higher than that at Kapsabet Bridge, Kipkaren Bridge and Bondeni estate (Figure 3). The lowest mean concentration of cadmium (0.015±0.001mg/L) was recorded upstream in Kaptagat and downstream in Turbo. The highest mean concentration of Cadmium at Naivash carwash was above the recommended guideline of NEMA (0.01mg/L) and WHO (0.003mg/L). This poses a health risk.

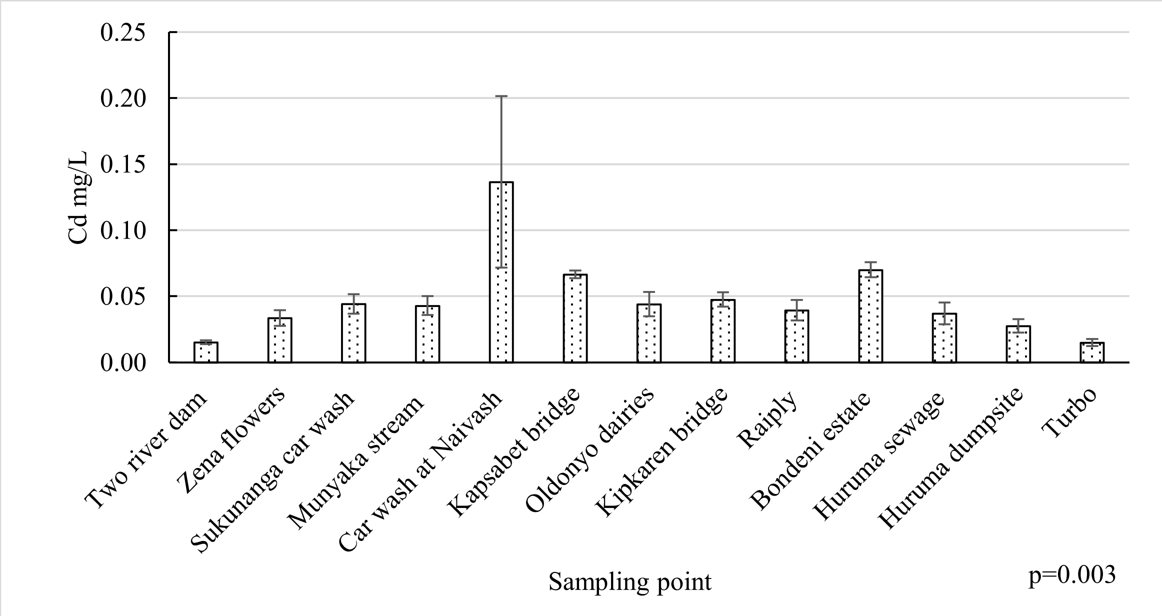

Figure 3: Cadmium concentration along Sosiani River
Source: Survey Data, 2016

Levels of Cadmium also varied along the river longitudinally and with the onset of the wet season P< 0.023 (Table 3). This is attributed to waste oil washed off from vehicle engines and discarded old batteries. This is followed by Huruma sewage treatment plant and municipal effluent discharge point at Kapsabet Bridge and Rai plywood factory. This could be attributed to many motor vehicle garages at Bandaptai where Cadmium is found in rechargeable batteries discarded around (Ni-Cd batteries). Cadmium is also found in municipal effluent washed off from many products like paints, photography, food products, detergents and body care products (Ulmgren, 2001, Perry *et al.*, 2007).

The concentration of cadmium were above the recommended NEMA and WHO standards for drinking water and water for recreation purposes hence the water is not safe for drinking. This raises health concern since Cadmium is toxic and bio-persistent. It has acute and long term toxicity in mammals and is a powerful mutagenic agent (Adriano, 2001, Apostolis *et al.*, 2007; Luoma & Rainbow, 2008).

3.3 Variations in Lead Levels

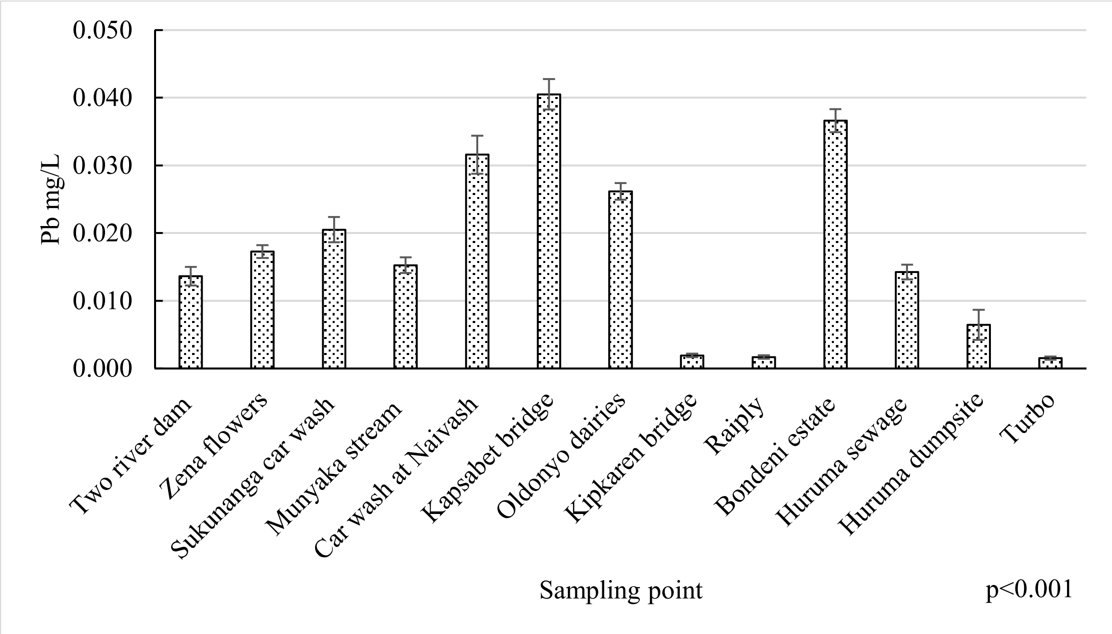

Figure 4: Lead concentration along Sosiani River
Source: Survey, Data, 2016

Lead concentration varied significantly along the Sosiani river F= 72.26 P<0.001(Table 4.3). There was a gradual increase in lead concentration from Two River Dam 0.014±0.0014mg/L downstream (Fig. 4). The highest concentration of lead was recorded at Kapsabet Bridge (0.0405±0.0022mg/L) followed by Bondeni estate 0.0366±0.0017mg/L and Naivash carwash 0.0316±0.0028mg/L respectively. This can probably be attributed to heavy metal contamination from human waste and industrial activities like Eldoret steel mills, vehicle garages and petrol stations. The lowest lead concentration was recorded downstream in Turbo 0.002±0.0002mg/L which indicates that the river has some self cleansing ability.

Levels of lead also increased with onset of rainy season as a result of increased run-off. However, it is noted that the levels of lead concentration in this river were below the NEMA guidelines (0.05mg/L) but above the WHO standards (0.01mg/L). The levels of lead increased significantly with the onset of the rainy season P<0.004. Lead poisoning causes neuro-development disorders, cardiovascular diseases, euceophalopathies, anaemia, renal malfunctioning and various endocrinal disorders especially of the reproductive glands hence impaired fertility (WHO, 2011).

3.4 Variations in Chromium Levels

Chromium concentration varied significantly along Sosiani river (F=140.26 P<0.001). This varied from Two river Dam upto downstream in Turbo (Figure 5). The highest concentration of chromium was at Rai plywood industries discharge point (0.0626±0.0043mg/L).

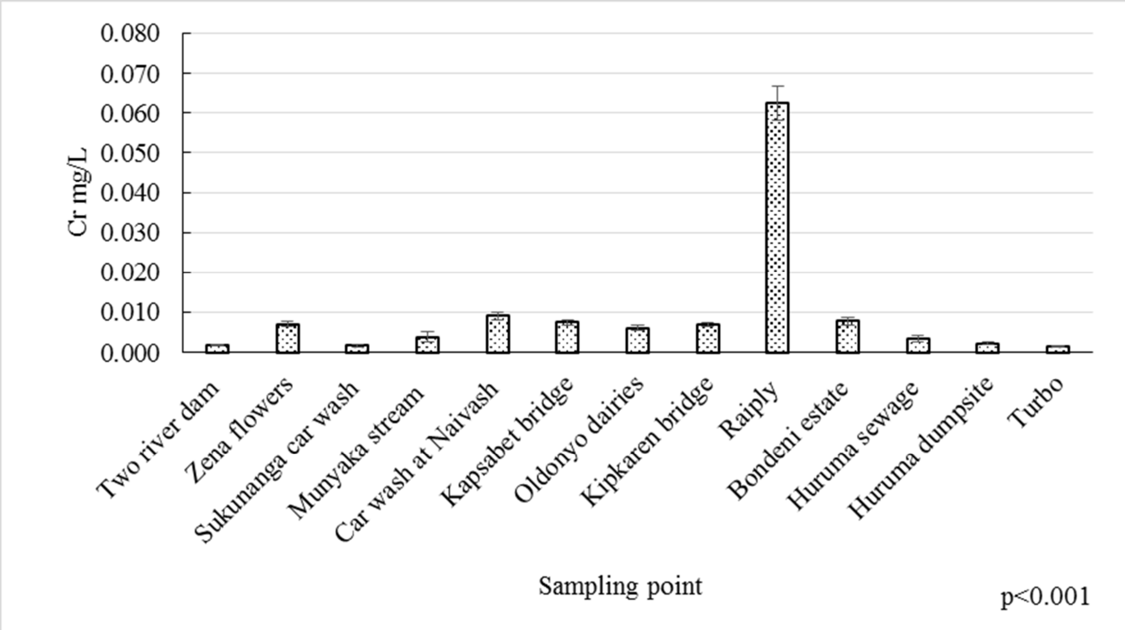

Figure 5: Chromium concentration levels along Sosiani River

Source: Survey Data, 2016

Levels of chromium at Rai plywood were above the recommended WHO standards (0.05mg/L). NEMA guidelines recommend a maximum of 0.1mg/L of chromium in recreational waters and 1.5mg/L for irrigation purposes but is silent on drinking water standards hence the WHO standards for chromium was used.

The mean levels increased midstream in town centre as more effluent was discharged into the river from various industries. This is attributed to use of Chromium in wood preservatives which are common in Eldoret town. Chromium is discharged from diffuse sources and products such as preservatives, lubricants, oils, paints, pesticides, faecal matter, leather industry, stainless steel plants, dying, wet textile processing and tanning activities. Chromium III is widely used as a tanning agent in leather processing (David, 2008). The levels of chromium also declined downstream at Turbo discharge point (0.002mg/L). However, it was observed that the levels of chromium increased with the rainy season though not significantly ($P< 0.138$).

All these metals reduced significantly downstream in Turbo perhaps due to self purification ability of rivers. Running water purifies itself through dilution of polluted water with the influx of surface and ground water or through certain complex hydrologic, biologic and chemical processes such as sedimentation coagulation, volatization and precipitation of colloids or subsequent settlement at the base of the river channel and biological assimilation (Alavi *et al.*, 2007).

These findings on heavy metals are consistent with similar studies on spatial distribution of metals along agro-industrial effluent sites along the riparian of Nzoia River where heavy metals: zinc, lead, copper and cadmium displayed asymptotic trends with distance and were higher in sediments (Omutange, 2010). Similarly, studies on Njoro River revealed high concentration of copper, lead, cadmium and arsenic along a gradient of human activities and increased during rainy seasons (Ndaruga *et al.*, 2004). Distribution of metals were also found to be high in rivers Nyando, Sondu Miriu, Nzoia, Yala, Awach, Kibos and Kasat especially aluminiun, manganese and iron which also increased during rainy seasons (Bukhalama, 2001 and Mwamburi, 2003). In another study on Lake Victoria metal concentrations were found to be above recommended values for drinking water and increased during rain seasons. Levels of lead zinc and mercury were found to be high (Tole & Shitsama, 2003; Ochieng, 2007). The results corroborate findings by Marimba, (2003) who established that heavy metals exhibited differential patterns that declined along Sosiani River downstream. Gichana *et al.*, (2014) also observed significant variation ($p<0.05$) of physical chemical and microbiological parameters downstream of River Nyangores in the Maasai Mara River Basin which increased during the wet season.

4. Conclusions

River Sosiani contains heavy metals in varying proportions which exhibited both seasonal and spatial distribution. The concentrations of heavy metals were lowest upstream at the source of the river but increased midstream through Eldoret town perhaps as the river drained effluent discharged from several anthropogenic activities. However, further downstream of Eldoret town in Turbo the concentration of heavy metals declined which perhaps shows self purification ability of Sosiani River. The concentrations of the heavy metals in water also increased during rainy season which can be attributed to increased surface runoff which drains effluent into this river. The highest concentration of zinc was recorded at Kapsabet Bridge 0.455±0.007mg/L since Municipal effluent is a major source of Zinc in Sosiani River. On the other hand the highest levels of cadmium were recorded at Naivash carwash 0.137±0.065mg/L due to waste from vehicle engines while the highest concentration of lead was recorded at Kapsabet Bridge (0.0405±0.0022mg/L). The study also found out that the highest concentration of chromium in this river was at Rai plywood industries discharge point (0.0626±0.0043mg/L) due to wood preservatives and glue used in the plywood process. In general, levels of Zinc and Chromium were below both NEMA/WHO standards but Cadmium and lead concentrations are above NEMA/WHO standards which pose a risk to human health.

5. Recommendations

The County government of Uasin Gishu and Eldoret and Water Sanitation Company (ELDOWAS) should channel Municipal effluent and storm drain into effluent treatment works for pre-treatment. Water Resource Management Authority (WRMA) and National Environment Management Authority (NEMA) should enhance enforcement of waste water regulations which require all facilities discharging effluent to construct wetlands if not connected to the sewer line. ELDOWAS should include chemical treatment in Huruma sewage treatment plant to improve the efficacy of treatment of heavy metals. They should also construct a wetland and introduce wetland plants to manage the nutrients from this sewage water like water sedge and Nile cabbage instead of discharging directly into Sosiani River.

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